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An Optimization and Assessment on DG adoption in Japanese Prototype Buildings

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Abstract

This research investigates a method of choosing economically optimal DER, expanding on prior studies at the Berkeley Lab using the DER design optimization program, the Distributed Energy Resources Customer Adoption Model (DER-CAM). DER-CAM finds the optimal combination of installed equipment from available DER technologies, given prevailing utility tariffs, site electrical and thermal loads, and a menu of available equipment. It provides a global optimization, albeit idealized, that shows how the site energy loads can be served at minimum cost by selection and operation of on-site generation, heat recovery, and cooling.

Five prototype Japanese commercial buildings are examined and DER-CAM applied to select the economically optimal DER system for each. The five building types are office, hospital, hotel, retail, and sports facility. Based on the optimization results, energy and emission reductions are evaluated. Furthermore, a Japan-U.S. comparison study of policy, technology, and utility tariffs relevant to DER installation is presented. Significant decreases in fuel consumption, carbon emissions, and energy costs were seen in the DER-CAM results. Savings were most noticeable in the sports facility, followed by the hospital, hotel, and office building.

Keywords: distributed energy resources, combined heat and power, building energy efficiency, commercial buildings, optimization

Introduction

The Japanese Ministry of Economy, Trade and Industry (METI) is setting a new Long-Term Energy Supply and Demand Strategy to 2030. An interim report released in June 2004 proposes more decentralized energy systems (or microgrids), and this new outlook includes a distributed generation development scenario wherein the share of self generation in total electricity supply exceeds 20% by 2030 (METI, 2004). This research conducts a survey of the potential for DER utilization and the installation of PV in Japan. As part of this research, a database of DER technologies, Japanese energy tariffs, and prototypical building energy loads has been developed and can be used for future energy efficiency research. Using the Distributed Energy Resources Customer Adoption Model (DER-CAM), an investigation was conducted of economically optimal DER investments for different prototype buildings in Japan. The

potential for DER in Japan and the resulting energy savings and environmental effects has been determined. Additionally, a comparison of the DER investment climate in Japan to that in the United States has been conducted.

Method

DER-CAM

Developed by the Lawrence Berkeley National Laboratory (LBNL) in the United States, DER-CAM is an optimization tool for DER technology selection. DER-CAM minimizes the annual energy cost of a given customer, including DER investment costs, based on input data covering DER technology cost and performance, electricity and natural gas tariffs, and hourly end-use energy loads, such as space heating, space cooling, domestic hot water, etc. DER-CAM reports the optimal technology selection and operation schedule to meet the end-use loads of the customer.

Utility Tariffs in Japan

Utility electricity and gas tariffs are key factors determining the economic benefit of a CHP installation. In Japan, there are three main components to each commercial building monthly electricity bill: 1. a fixed customer charge (\$/month); 2. a demand

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charge proportional to maximum power consumption during the month (\$/kW-month) (a typical monthly demand charge is around 10-18 \$/kW-month); and 3. a time-of-day and seasonally varying energy charge (\$/kWh) (the energy price ranges from 0.08 to 0.18 \$/kWh for on-peak power, and 0.04-0.05 \$/kWh off-peak, which is close to the level of the more expensive U.S. regions).

Natural gas tariffs in Japan are roughly two to three times higher than in the U.S. Even the favorable rate for cogeneration sites is still higher than typical U.S. rates. The rate for buildings with cogeneration has an around 0.0306 \$/kWh energy charge, a 64 \$/month customer charge, and a 8.21E-04 \$/kWh maximum seasonal charge (a special surcharge on gas consumption from Dec.-Mar.). Additionally, an unusual flow rate charge is also levied monthly in Japan, based on annual maximum hourly consumption (a typical monthly charge is 8.3 \$/m³-h). A typical gas price for CHP in Japan is from 0.033 to 0.05 \$/kWh. Note that the exchange rate used was that of October, 2003: US\$1 = 120 ¥, EURO 1 = US\$1.07.

DER Technology Information in Japan

For this study, data was collected on Japanese DER equipment. Fig. 1 compares DER turnkey costs in Japan and the U.S. There is little difference in the range 3,000 kW to 5,000 kW. At higher capacities, Japanese prices are lower, while at the lower capacities, Japanese prices are significantly higher.

Selection of Building Size

Fig. 2 shows the average distribution of construction floor area distribution for various building types in Japan. This data is from The Ministry of Construction's (present Ministry of Land, Infrastructure and Transport) "Construction Data and Statistics Annual Report". Most office buildings are below 5,000 m² but there are many above 10,000 m² and under 2,000 m². The five prototype buildings considered are: office building, hospital, hotel, retail, and sports facility. An average commercial building size of 10,000 m² was used as the representative floor area size for all buildings.

Building Load

Detailed knowledge of energy end-use loads is important for selecting an appropriate DER system. In Japan, when designing CHP systems, estimates of energy consumption intensities of various building types are typically obtained from the Natural Gas Cogeneration Plan/ Design Manual 2002 (Kashiwagi, 2002). This manual reports annual energy consumption and proportion of consumption by month and hour. Hourly loads can be estimated from this data. It is derived from actual buildings throughout Japan and although not differentiated by climate it was

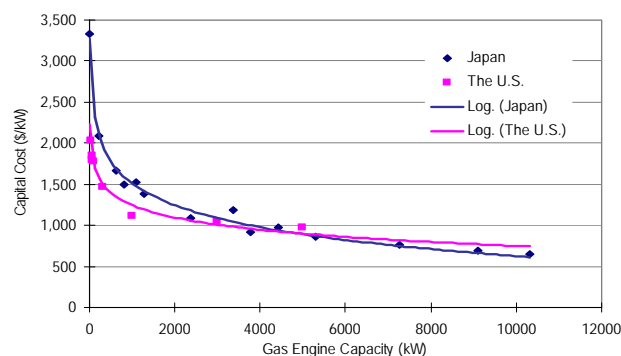


Fig. 1. Comparison of turnkey CHP costs in Japan and the U.S.

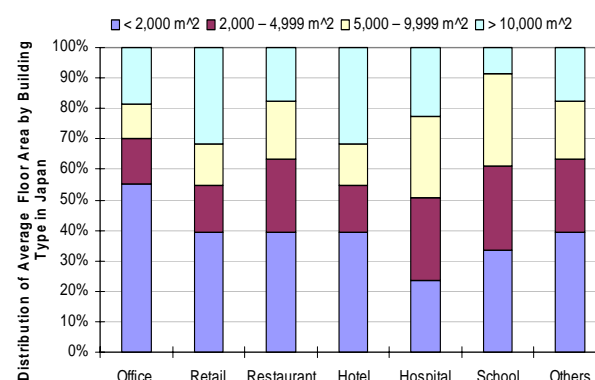


Fig. 2. Distribution of Average Construction Floor Area by Building Type

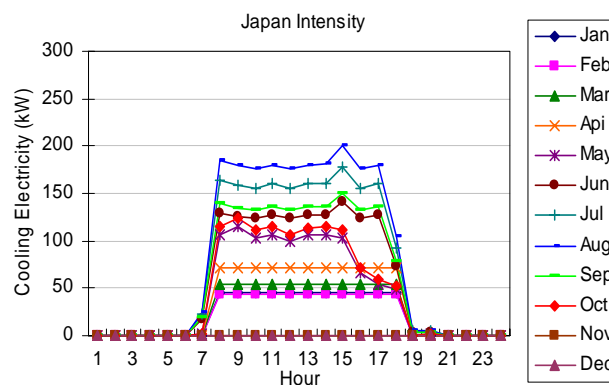


Fig. 3. Cooling Electricity Load

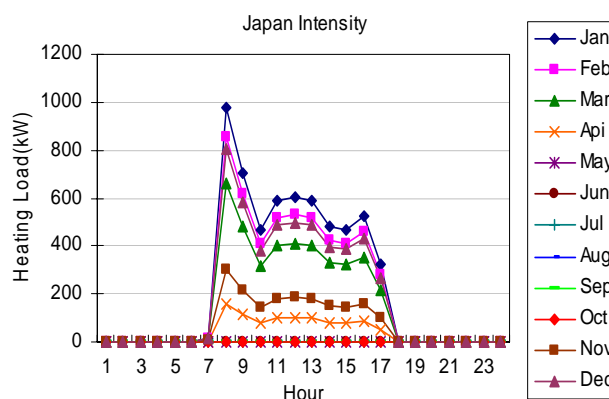


Fig. 4. Heating Load

used for this research.

Examples of hourly load shapes (cooling and space heating) for an office building are shown in Fig. 3 and Fig. 4). Significant seasonal differences can be seen in cooling and space heating load, which is attributed to the variable typical climate in Japan. The cooling electricity loads are 150 -200 kW during the summer and 50 -70 kW during fall and spring, while the space heating loads are approximately 500 - 600 kW with a peak load of 974 kW in the winter. Although which are not shown in the figures, the electricity loads vary from 300-400 kW throughout the year. The hot water loads mostly occurs around noon (lunch break) with a peaks at 32 kW at 12 P.M in the winter.

Other Parameters

DER-CAM optimizations were done assuming a DER subsidy (typically, 1/3 of the installation cost). The average efficiency of the Japanese macrogrid was assumed to be 36.6%. CO₂ emissions were assumed to be 0.66 kg/kWh (fossil fuels, only), equivalent to carbon emissions of 0.18 kg/kWh .

In the results, whole system efficiency is the percentage of energy from fuel used by the DER system that is applied to an end use as either electricity or heat. In the U.S., the Federal Energy Regulatory Commission (FERC) uses an alternative definition of efficiency that is also reported, herein referred to as the FERC efficiency, which is defined as:

$$\text{FERC Efficiency} = \frac{[\text{Electrical Energy Produced}] + 1/2 [\text{Recovered Heat Utilized}]}{[\text{HHU of Fuel Consumed}]} \times 100\%$$

For each building type modelled, three DER-CAM scenarios were considered:

- Do-Nothing: No DER investments are allowed. This scenario provides the baseline annual energy cost, consumption, and emissions prior to DER investment.
- DER: DER investment in electricity generation only, no CHP allowed.
- DER with CHP: DER investment in any of the electricity generation and heat recovery and utilization devices.

Results for Prototype Buildings

CHP shifts the balance of utility purchases of electricity and natural gas in several ways. Operating generation equipment reduces utility electricity purchases and increases natural gas purchases. Recovered heat from the equipment can be used to offset natural gas used for heating and/or electricity used for cooling. Examples of office and hospital building are shown below.

Office:

Even for office buildings, which have low capacity factors, on-site generation is economic because of high on-peak electricity prices and demand charges,

combined with discounted CHP natural gas rates. Table 1 shows example DER-CAM results for the office building: The Do-Nothing total energy bill is \$317,400. In the DER without heat recovery scenario, a 300 kW natural gas engine was selected, resulting in decreased electricity purchases and increased natural gas purchases. Total annual energy costs (including the capital and maintenance costs) are reduced by about 4.7% (\$15,000). For the DER with CHP scenario, the 300 kW natural gas engine with heat recovery for heating and absorption cooling was chosen. Compared with the Do-Nothing case, the total annual energy bill savings are 12.3% (\$40,000) with a payback period of 4.7 years. Fig. 5 and Fig. 6 show the January weekday natural gas loads and how they are met by the CHP system. The peak load is 1200 kW at 8 am, and 600 kW is met by the recovered heat from CHP. Fig. 7 and 8 show the electricity loads on a summer (July) day and how the recovered heat was used to meet the load. The peak electricity load is 569 kW, 300 kW of which is met by DER. The peak cooling electricity load (177 kW) is reduced by absorption cooling, and the electricity purchase from the macrogrid is reduced to 198 kW.

Hospital

For hospital, the Do-Nothing total energy bill is \$332,920. No equipment was selected for DER without heat recovery: there is no change in cost or efficiency from the Do-Nothing case. For DER with CHP, a 300 kW natural gas engine with heat recovery for heating and absorption cooling was chosen. Compared with the Do-Nothing case, the total annual energy savings are 21.1% (\$70,310) with a payback period of 3.4 years. The annual fuel costs are reduced by 40%. Fig. 9 and Fig. 10 show the natural gas loads for winter (January) and how the load is met from CHP. The peak load is 1252 kW, of which 438 kW is met by the CHP system. Fig. 11 and Fig. 12 show the electricity loads in summer (July) and how the CHP system meets these loads. The electricity load at 10 A.M. is 311 kW; 300 kW is met by DER and 44 kW of the peak cooling electricity load (161 kW) is offset by absorption cooling, reducing the macrogrid electricity purchase to only 128 kW.

Comparative Results for All Prototypical Building:

Table 2 shows the installed capacity and capacity factors for the optimal CHP solutions for all prototype buildings. The capacity factor is defined as the ratio of electricity generated annually on-site to the full potential for generation.

Fig. 13 shows the peak load shift effect of CHP in the prototype buildings in both winter and summer. In the winter, the heating peak load of the sports facility is most significant, followed by hospital and office buildings. The biggest peak load reduction is seen in the sports facility (900 kWh), followed by the office building (550 kWh).

Table 1 Office Building DER-CAM Results

Case	Installed Capacity	Installed Technology	Installation Cost	Electricity Purchased		Gas (k\$)	Energy Cost	Total Cost	Energy Cost Reduction	Overall Cost Reduction	Pay Back Year
	kW		k\$	k\$	For DER	Gas only	k\$	k\$	%	%	a
Do-Noth ing	0	0	0	275.3	0	42.1	317.4	317.4			
DER	300	NG--00300	36.4	125.2	112	28.8	266	302.5	-16.2%	-4.7%	6.1
DER with CHP	300	NG-ABS HX-00300	58.5	83.8	129.4	6.7	219.9	278.4	-30.7	-12.3%	4.7

Table 2 Installed Capacity and Capacity Factors for the Optimal CHP Solutions

	Office	Hospital	Hotel	Retail	Sports facility
installed capacity (kW)	300	300	300	1000	600
capacity factor	49%	62%	72%	27%	56%

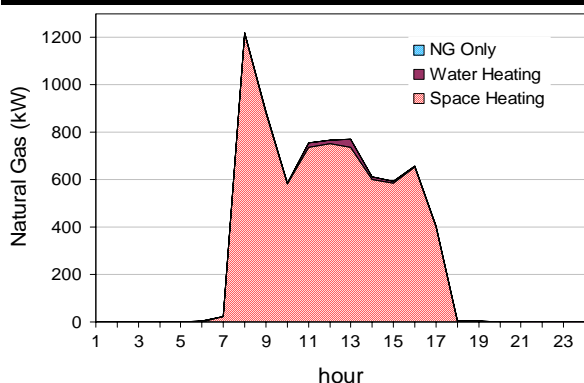


Fig. 5. Office Building January Natural Gas Loads

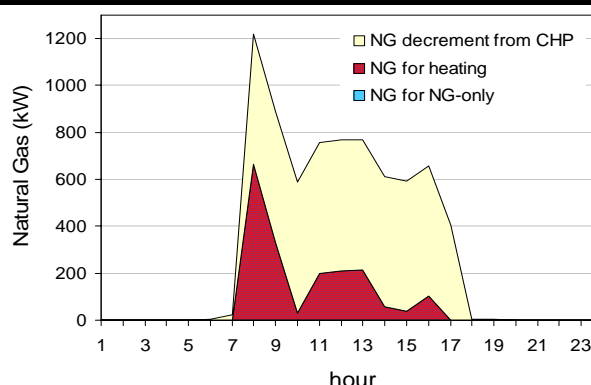


Fig. 6. Office Building January Natural Gas Load Provisions with CHP

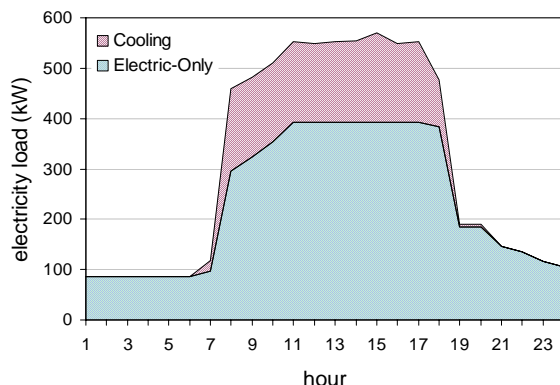


Fig. 7. Office Building July Electricity Loads

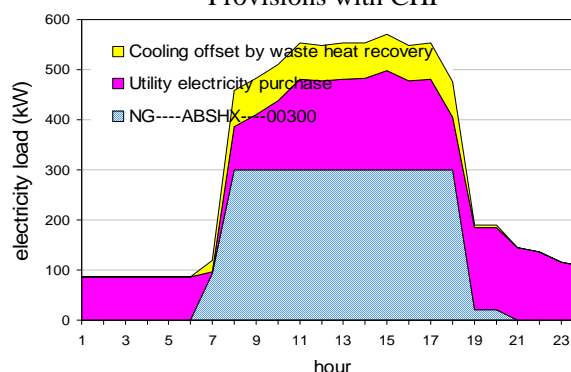


Figure 8: Office July Electricity Load Provision with CHP

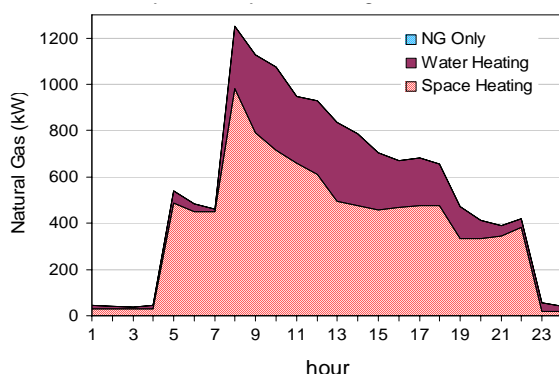


Fig. 9. Hospital January Natural Gas Load

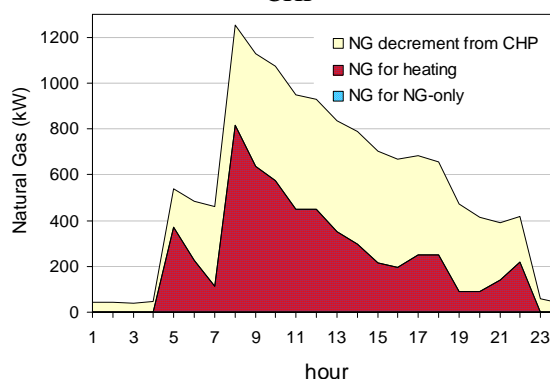


Fig. 10. Hospital January Natural Gas Load Provision with CHP

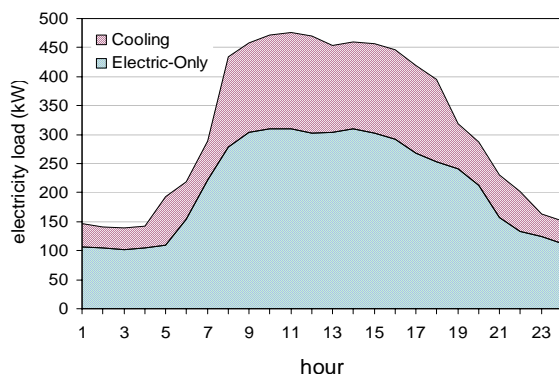


Fig.11. Hospital July Electricity Load

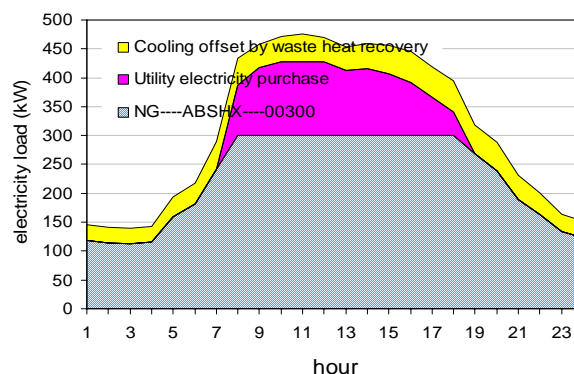


Fig. 12. Hospital July Electricity Load Provision with CHP

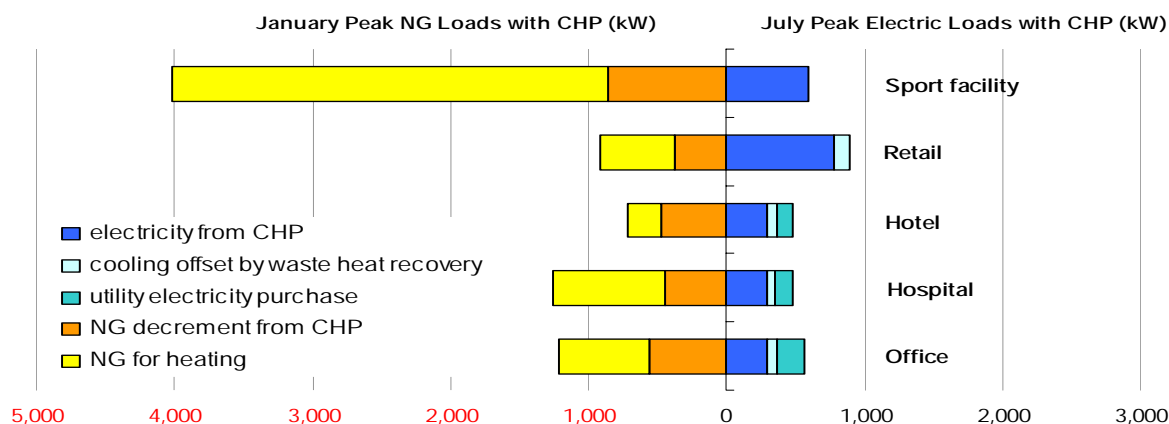


Fig. 13. The peak load shift effect of prototype building

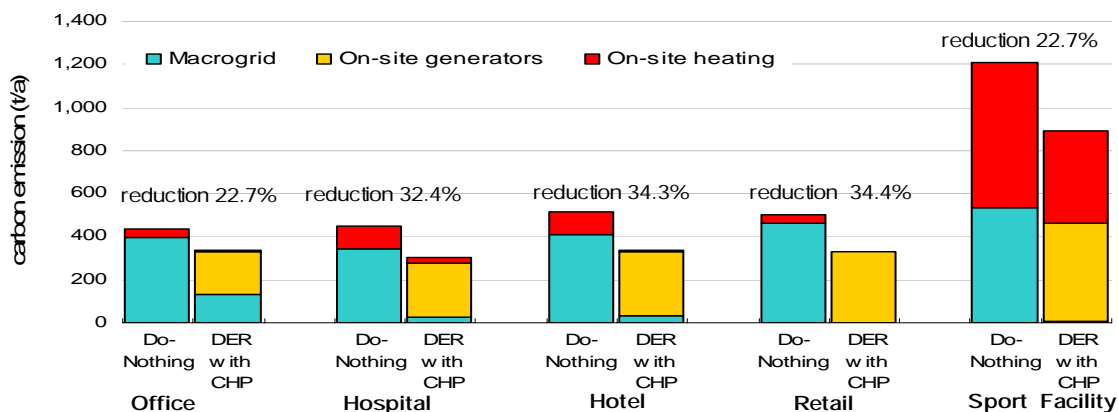


Fig. 14. The effect of prototype building carbon emission reduction

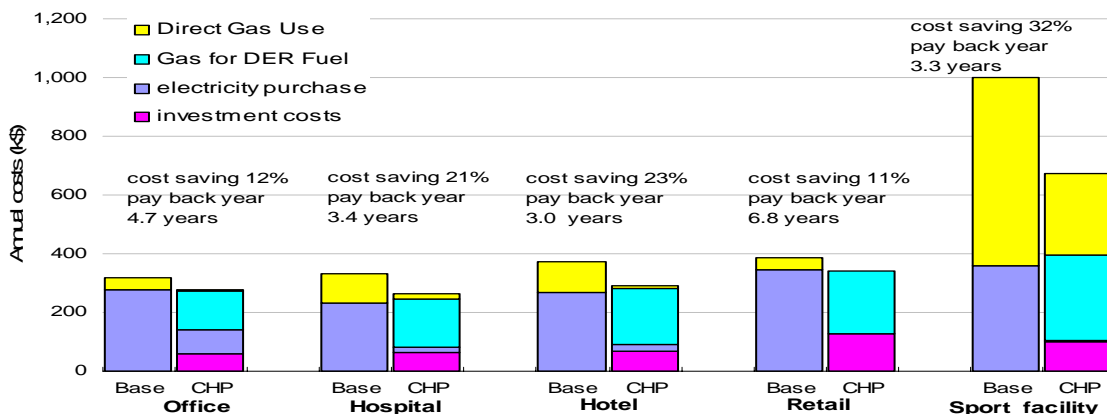


Fig. 15. The economic effect of prototype building

Table 3 Prototype building system efficiency improvement

	Office	Hospital	Hotel	Retail	Sports facility
Macrogrid Electrical Efficiency			36.6%		
Natural Gas to Heat Efficiency			80%		
Do-Nothing System Efficiency	42.1%	49.5%	48.3%	41.2%	64.1% ¹
DER Electrical Efficiency	31%		27.5%	34%	27.5%
DER with CHP System Efficiency	75%	74.1%	78%	69.4%	73.6%
DER with CHP System Efficiency (FERC)	53%	52.5%	54.5%	51.7%	52.3%
Whole System (DER & Util.) Efficiency	63.1%	72.2%	75%	69.4%	76.6%
Efficiency improvement (percentage points)	21	22.7	26.7	28.2	14.5

In the summer, the retail building shows the biggest utility electricity reduction; all peak loads can be economically met by the self-generated power and waste heat recovery from CHP. The effect of air conditioning by heat recovery is seen in all of the buildings except the sports facility, for which heat recovery for cooling is not economic.

CHP also shifts the amounts and sources of carbon emissions. Fig.14 shows the carbon emissions reductions, reported as: CHP installation reduces these emissions for all of the prototype buildings. This reduction is most significant for the hotel (34% reduction) and retail building (34% reduction), followed by hospital (32% reduction).

Furthermore, CHP shifts the amounts and sources of annual energy costs. Fig.15 shows the economics of CHP installation. For the sports facility, costs are reduced by 32%, followed by hotel (23%) and hospital (21%). The hotel has the shortest payback period (3.0 years), followed by sports facility (3.3 years) and hospital (3.4 years).

Table 3 states the system efficiency for the three scenarios. The entire system efficiency for all prototype buildings has been improved in all prototype buildings. The efficiency improvement is most significant for retail buildings (28.2 percentage point improvement), followed by hotel (26.7) and hospital (22.7). In all cases, the efficiency for DER without CHP is even lower than macrogrid efficiency.

CHP installation benefits all the prototype buildings considered, but hospitals, hotels, and sports facilities have the most potential benefit. Although benefits are not as great as for other building types, office buildings, which are traditionally not considered DER candidates, can also benefit.

Conclusions

This study examined five prototype commercial buildings and uses DER-CAM to select the economically optimal DER system for each. Significant decreases in fuel consumption, carbon

emissions, and energy costs were seen in the economically optimal results. This was most noticeable for the sports facility, followed the hospital and the hotel. This research demonstrates that office buildings can benefit from CHP, in contrast to popular opinion.

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¹ This is an overall efficiency of electrical efficiency and gas efficiency